Using Thermoelectric Coolers to Enhance Loop Heat Pipe Performance

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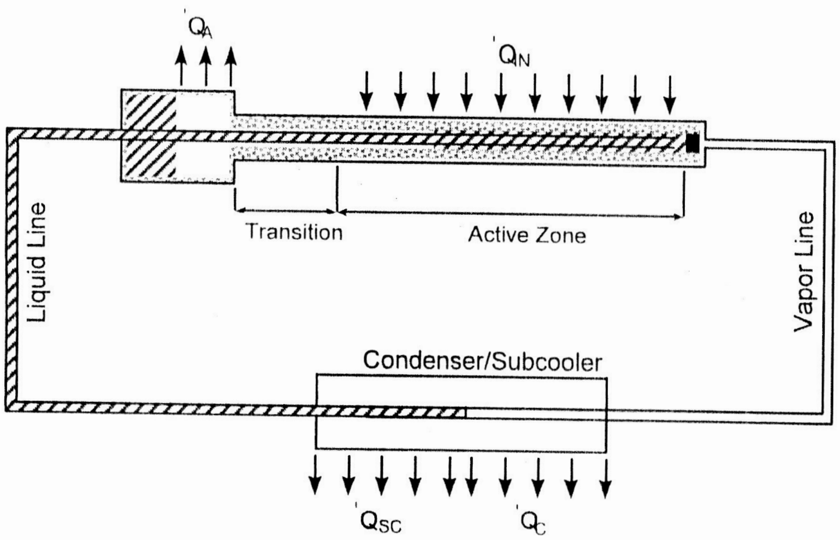
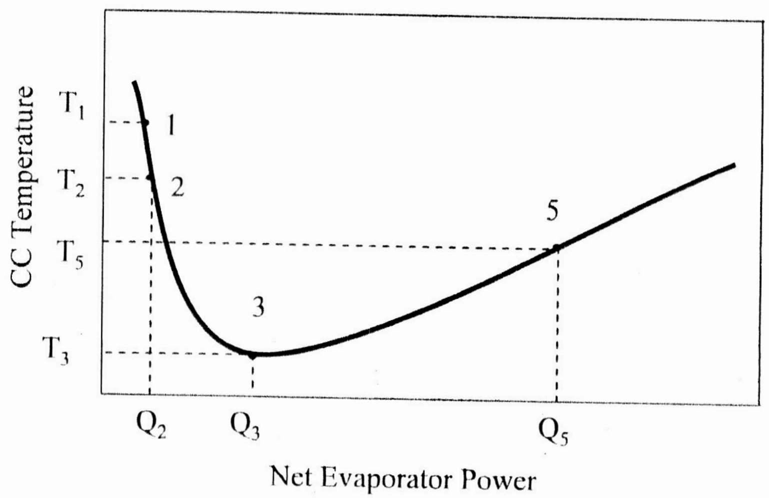
Outline

- LHP Operating Temperature
- LHP Start-up Issues
- How TECs Can Enhance LHP Performance
  - Start-up
  - Operating Temperature Control
- Experimental Studies
  - LHP with One Evaporator and One Condenser
  - LHP with Two Evaporators and Two Condensers
- Conclusions

LHP Operating Temperature
One Evaporator and One Condenser

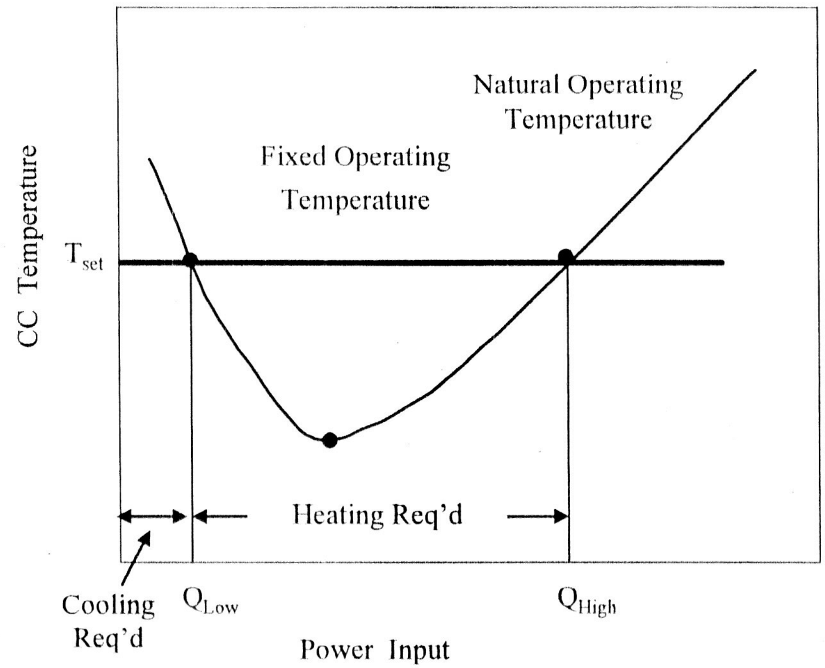
- **The LHP operating temperature is governed by the CC temperature.**
  - Heat leak from evaporator to CC
  - Subcooling of returning fluid
  - Interaction between CC and ambient
- **The CC temperature is a function of**
  - Evaporator power
  - Condenser sink temperature
  - Ambient temperature



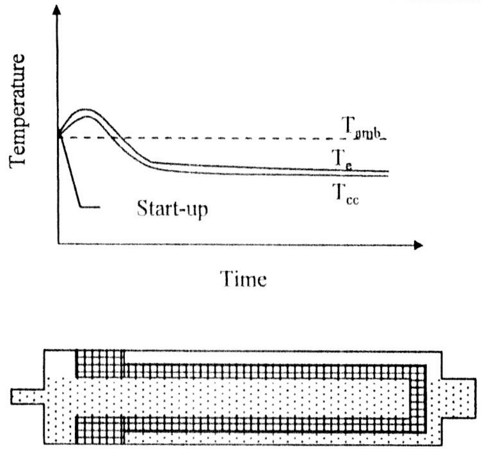


LHP Operating Temperature Control

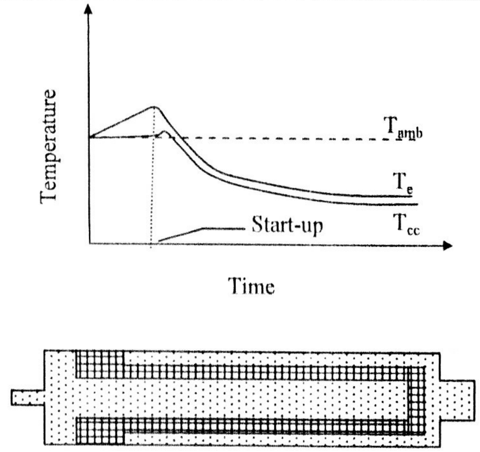
- State-of-the-art LHPs use electrical heaters to control the CC temperature.
  - Cold biased
  - Heating only, no active cooling
- TECs provide cooling as well as heating.
  - Cooling mode: expands temperature control to low power region
  - Heating mode: reduces control heater power requirement



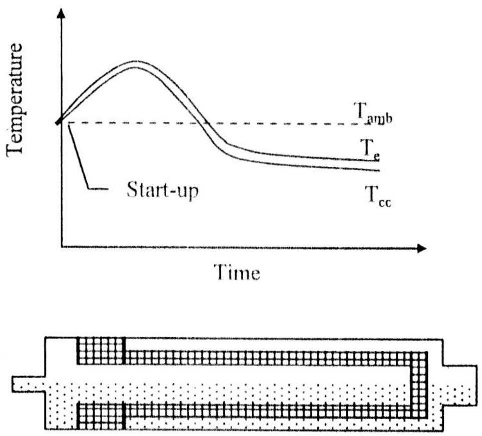
LHP Start-up Scenarios



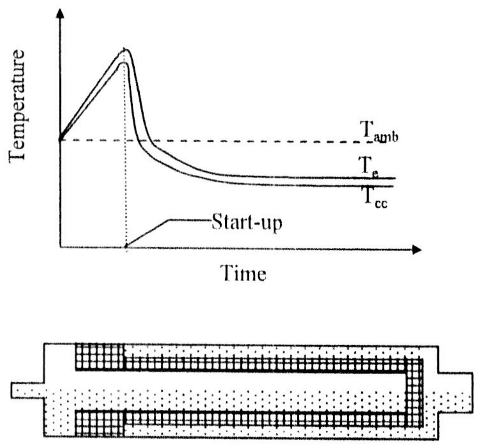
(a) Situation 1



(c) Situation 3



(b) Situation 2



(d) Situation 4

LHP Start-up Issues and TEC Solutions
Situation 4

- Without TEC (Figure A)
  - CC temperature rises with evaporator temperature due to heat leaks.
  - Required superheat may never be attained at low powers.
  - Starter heaters have been used to provide a highly concentrated heat flux for local boiling – 20W to 40W is required.
- With TEC (Figures B and C)
  - TEC can maintain a constant CC temperature to achieve the required superheat, resulting in a successful start-up.
  - TEC can also cool the CC to create the required superheat.
  - Starter heaters can be eliminated.

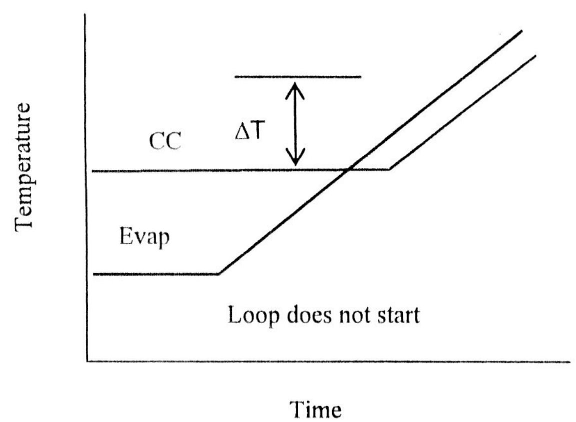


Figure A

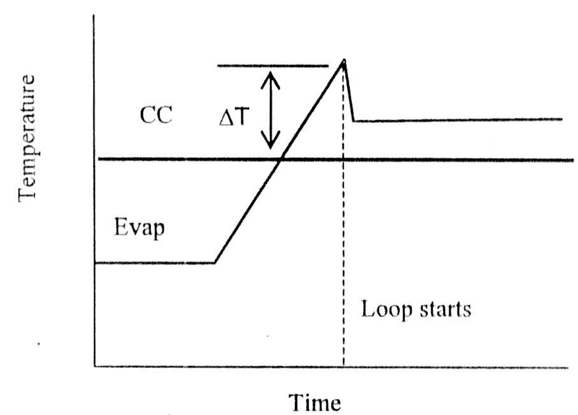


Figure B

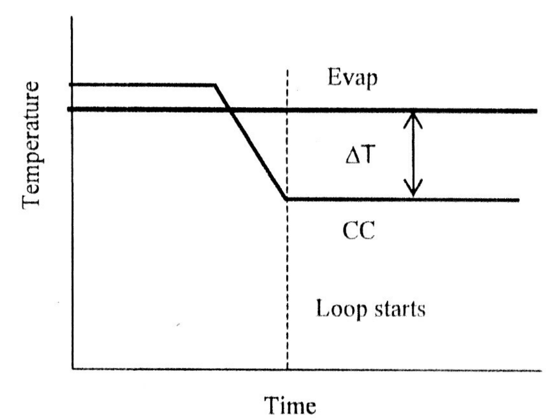


Figure C

LHP Start-up Issues and TEC Solutions
Situation 2

- Without TEC (Figure A)
  - Flow circulation starts after evaporator temperature rises above CC set point.
  - However the CC temperature may rise with evaporator temperature due to heat leaks.
  - Net heat load to evaporator decreases, leading to ever-increasing CC temperature, possibly violating the instrument maximum allowable temperature.
- With TEC (Figures B and C)
  - TEC can maintain a constant CC temperature, ensuring successful start-up and attainment of a steady state.
  - TEC can also cool the CC to start the loop.
  - Starter heaters can be eliminated.

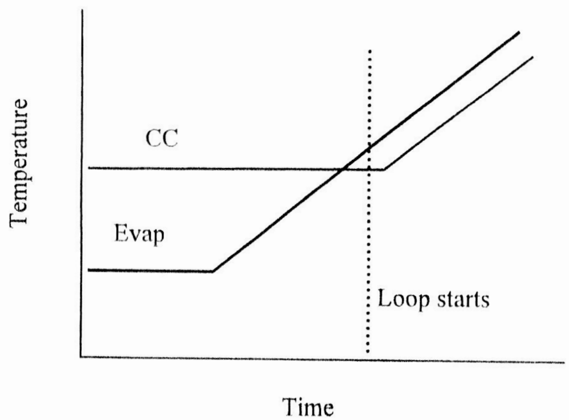


Figure A

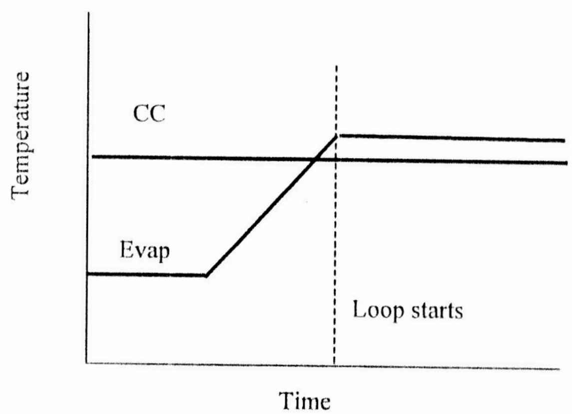


Figure B

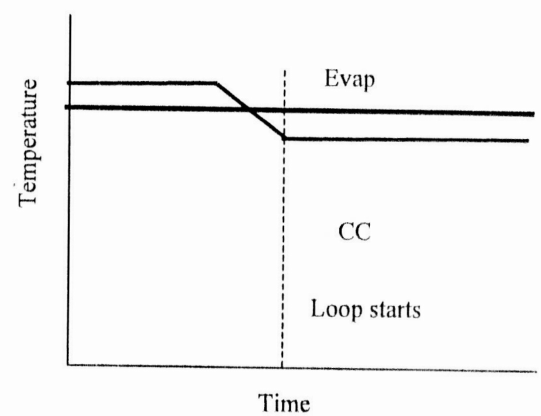


Figure C

Experimental Studies with Two LHPs

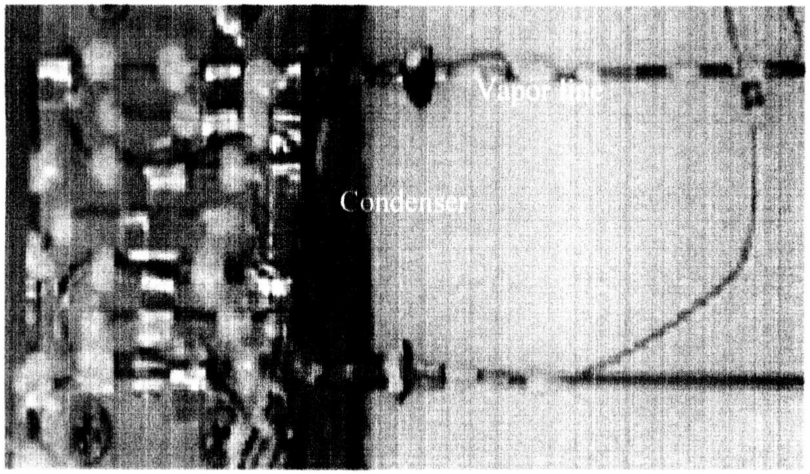
- Objectives
  - Demonstrate that TECs can be used to enhance LHP start-up success
  - Demonstrate that TECs can be used to control the CC temperature with small control powers
- Thermacore Miniature LHP
  - Single evaporator and single condenser
  - Evaporator size: 7mm O.D. x 50mm L
  - Tests performed with 0g, 117g, and 350g of thermal masses attached to the evaporator
- MLHP
  - Two evaporators and two condensers
  - Evaporator size: 15mm O.D. x 76mm L
  - Tests performed with 500 g thermal mass attached to each evaporator

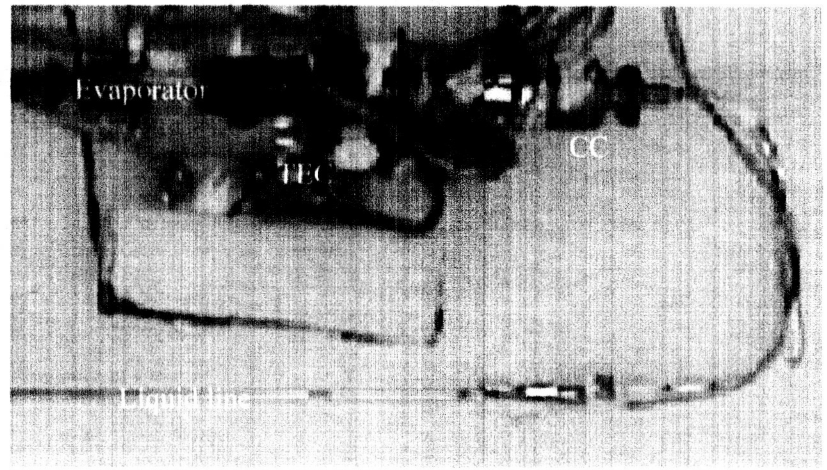
Design Summary of Thermacore Miniature LHP

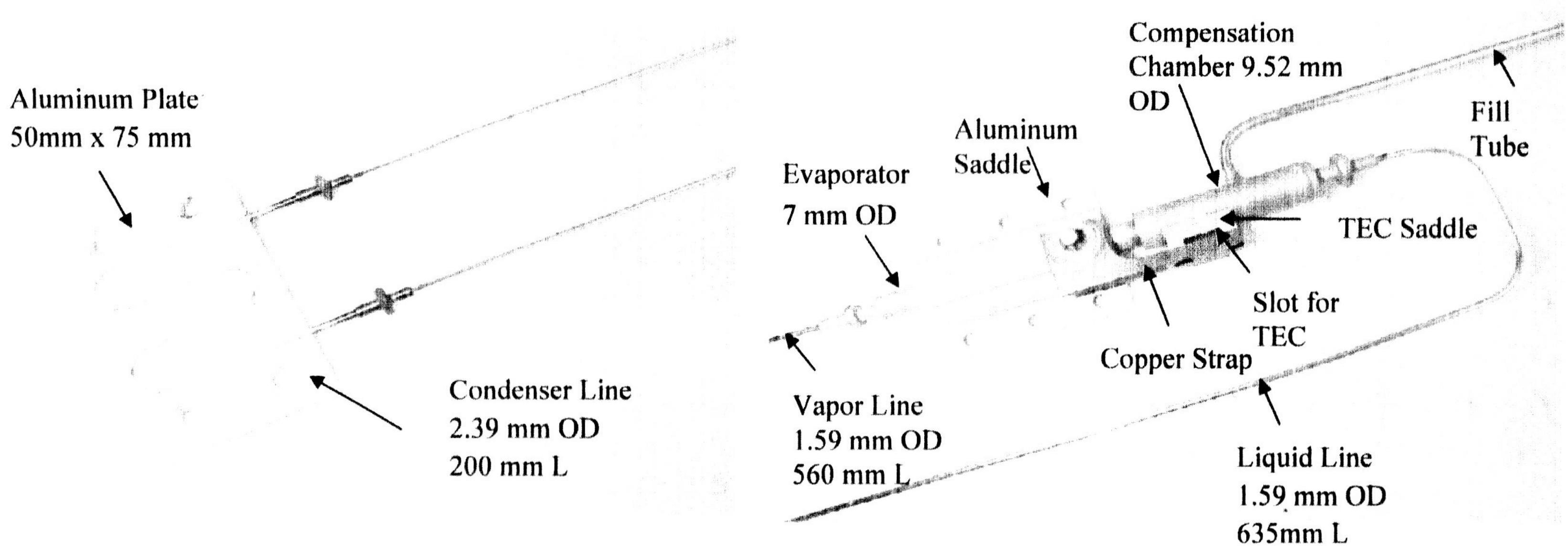
Item	Description
Evaporator	Aluminum Shell 7 mm O.D. x 51 mm L
Primary Wick	SS, 5.6 mm O.D. x 2.4 mm I.D 1.2 μm pore size, 1.0 x 10 -14 m^2 permeability
Secondary Wick	SS screen, 400 x 400 mesh
Compensation Chamber	SS 9.52 mm O.D. x 25.5 mm L
Vapor Line	SS, 1.59 mm O.D. x 560 mm L
Liquid Line	SS, 1.59 mm O.D. x 635 mm L
Condenser	Aluminum 2.39 mm O.D. x 200 mm L
Working Fluid	Ammonia, 1.5 grams
Total mass	79 grams

Pictures of Thermacore Miniature LHP

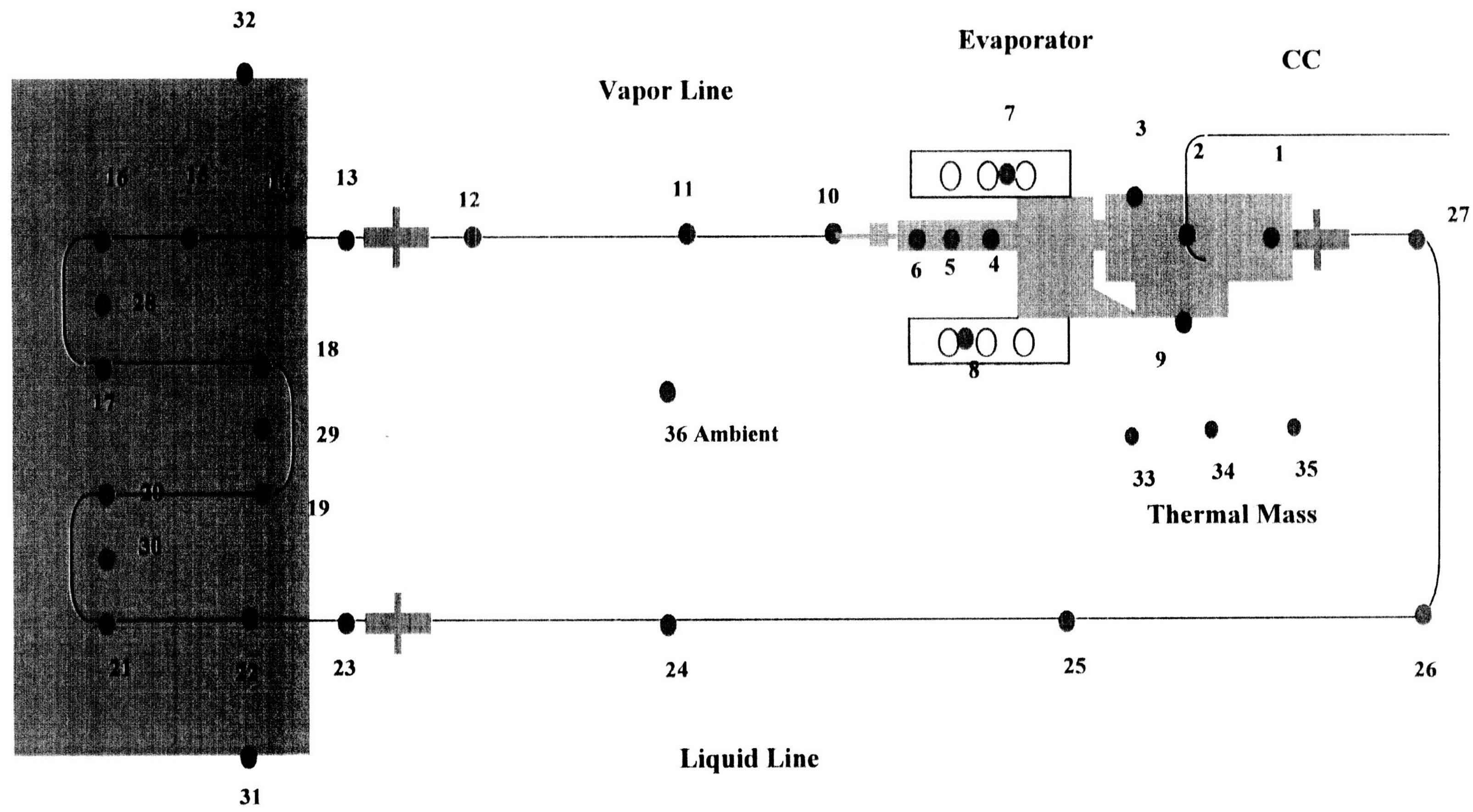
One Evaporator and One Condenser







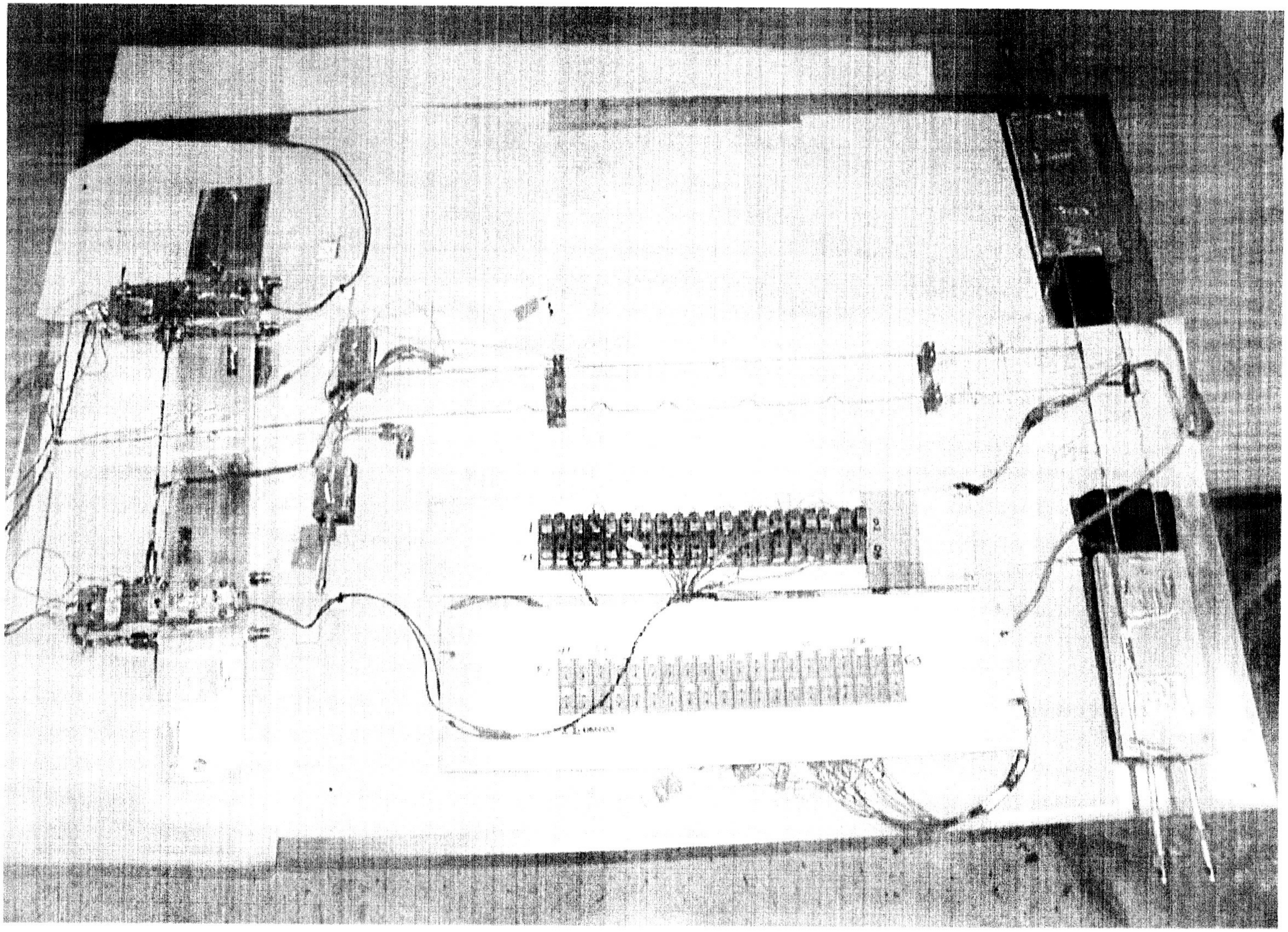
Schematic of Thermacore Miniature LHP



MLHP Design Parameters
Two Evaporators and Two Condensers

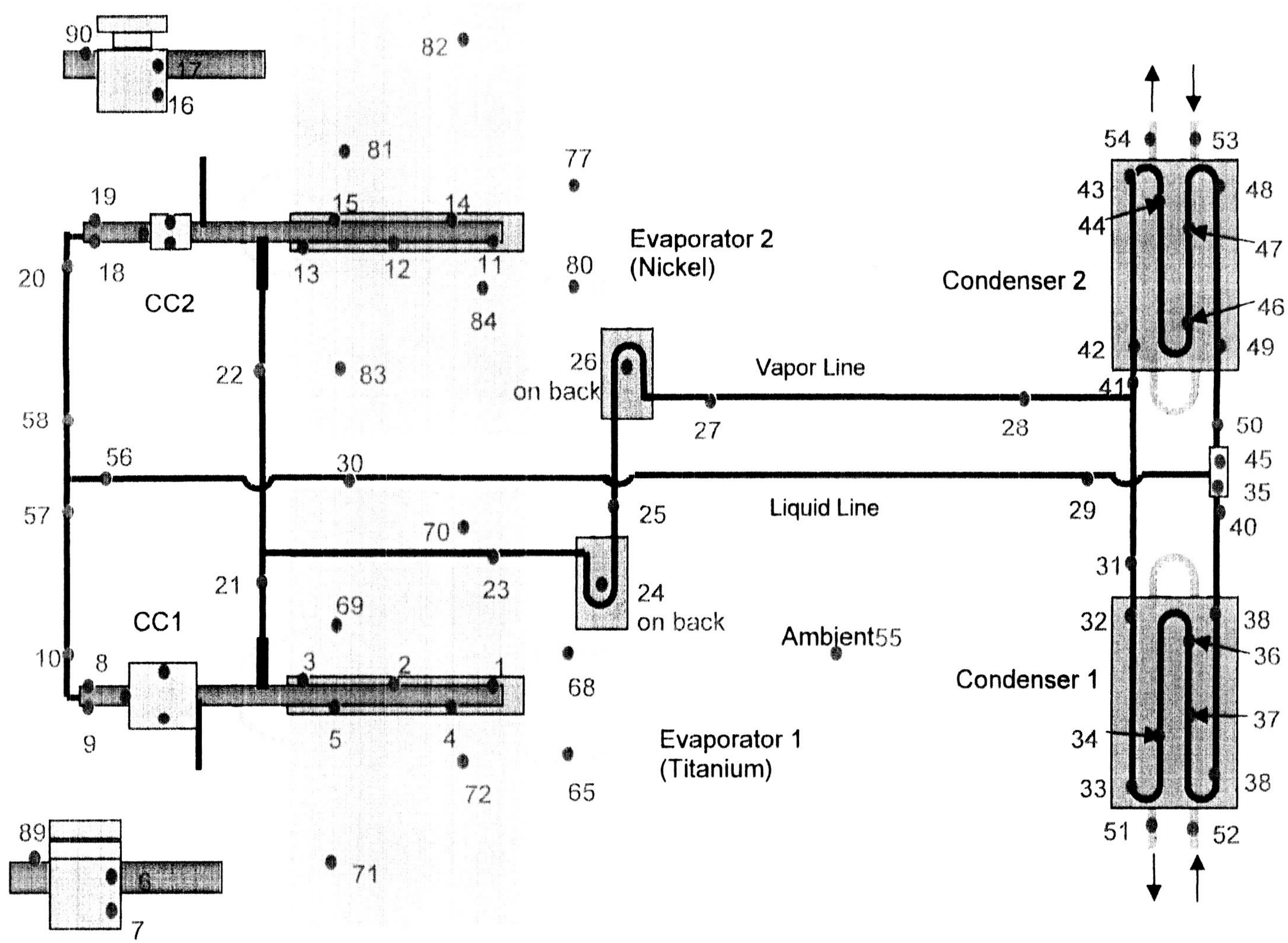
Component	Description
Evaporator (2)	Aluminum, 13mm O.D. x 76.2mm L each
Primary wick	Nickel, 0.6 μm pore radius, 60% porosity, 1.4x 10^{-14} m^2 permeability
Primary wick	Titanium, 3 μm pore radius, 60% porosity, 1.0x 10^{-14} m^2 permeability
CC (2)	Stainless steel, 18mm O.D. x 61mm L, 18cc each
Vapor line	Stainless steel, 2.38mm O.D. x 1200mm L
Liquid line	Stainless steel, 1.59mm O.D. x 1200mm L
Condenser (2)	Stainless steel, 2.38mm O.D. x 760mm L each
Flow regulator	Polyethylene wick, 40 μm pores
Working fluid	Anhydrous ammonia, 15.5 grams

MLHP Picture
(with Thermal Masses and TECs)

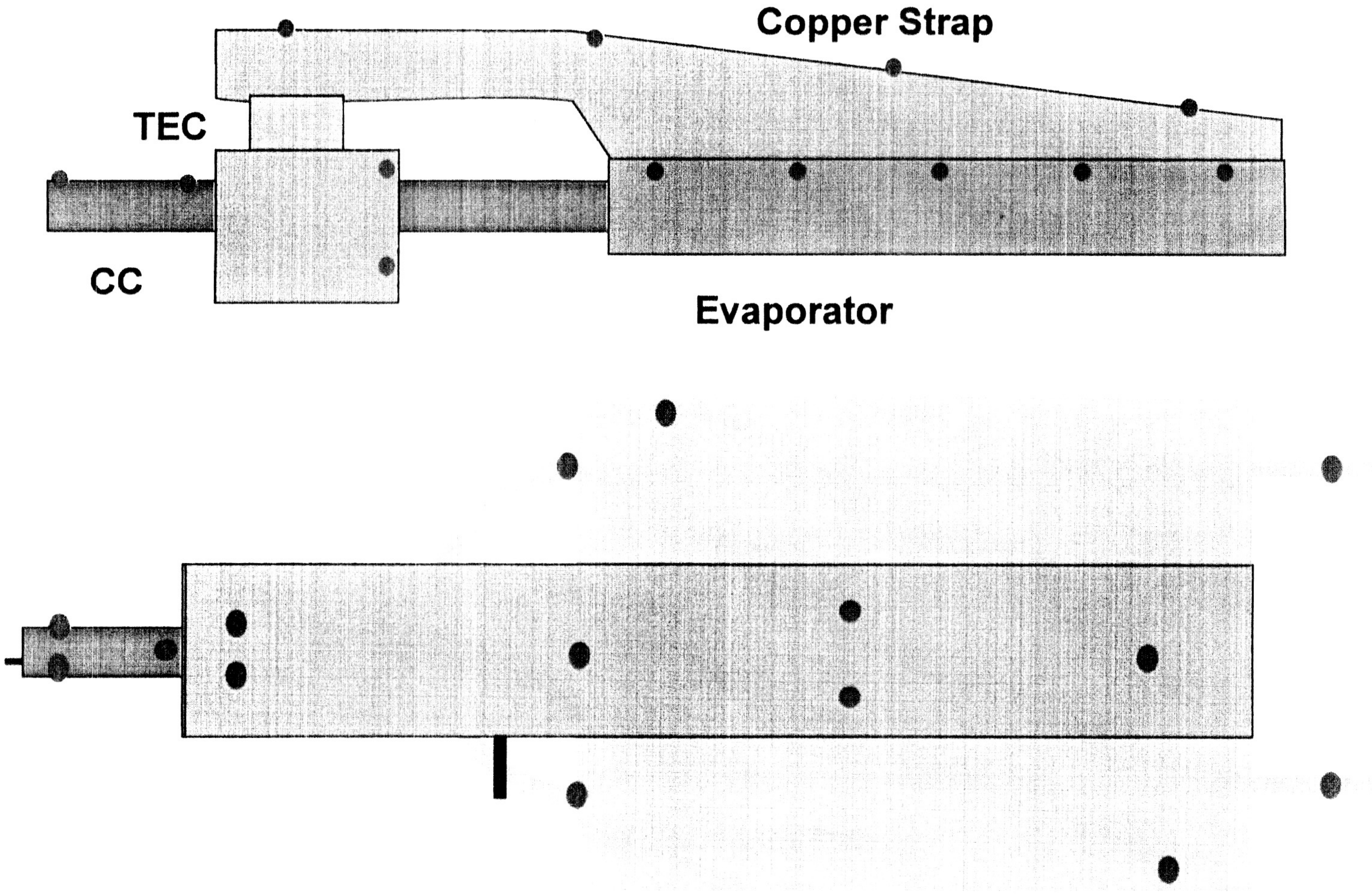


MLHP Schematic

Two Evaporators and Two Condensers

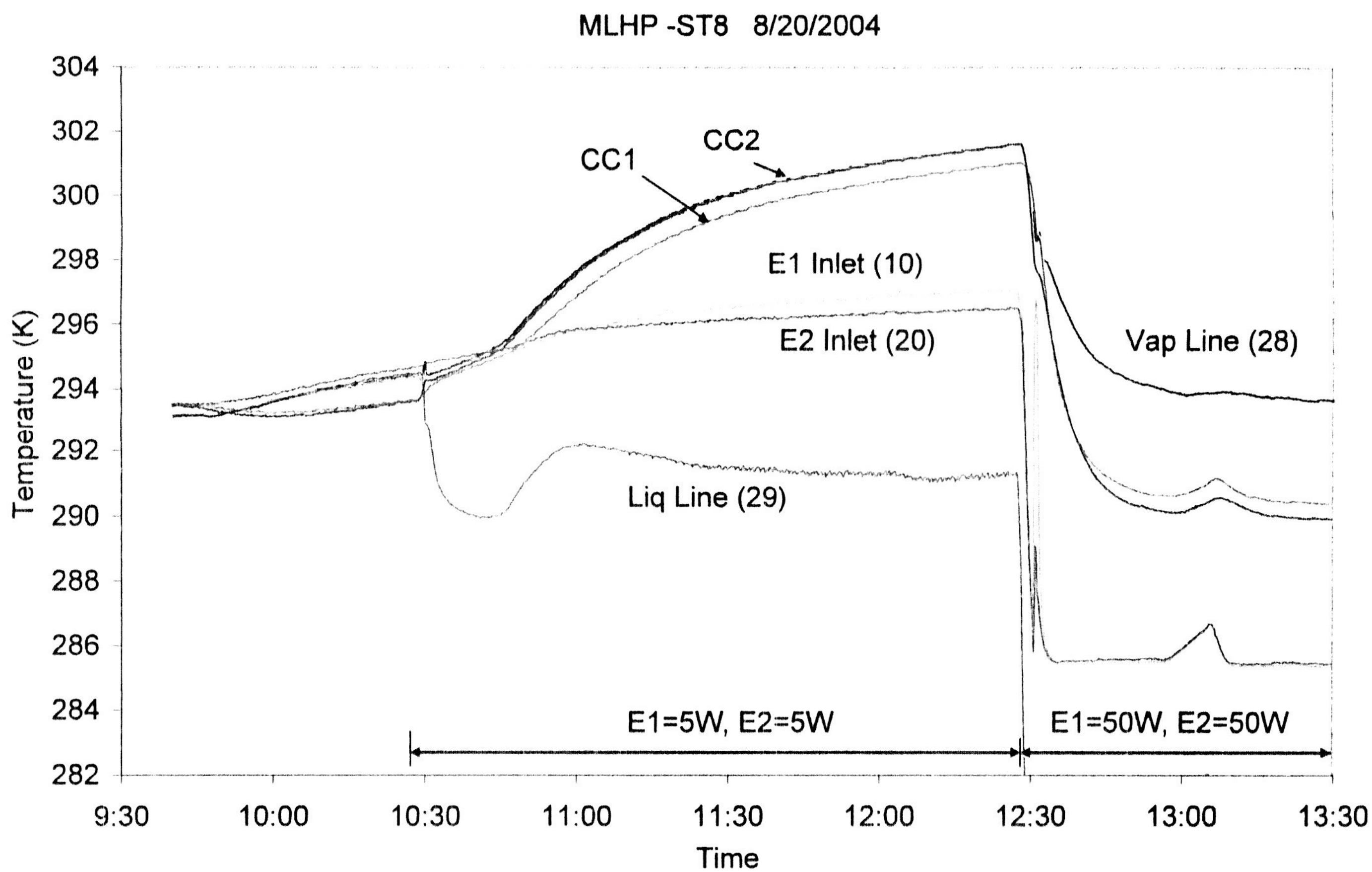


TEC Connections



MLHP Test Results - Star-up

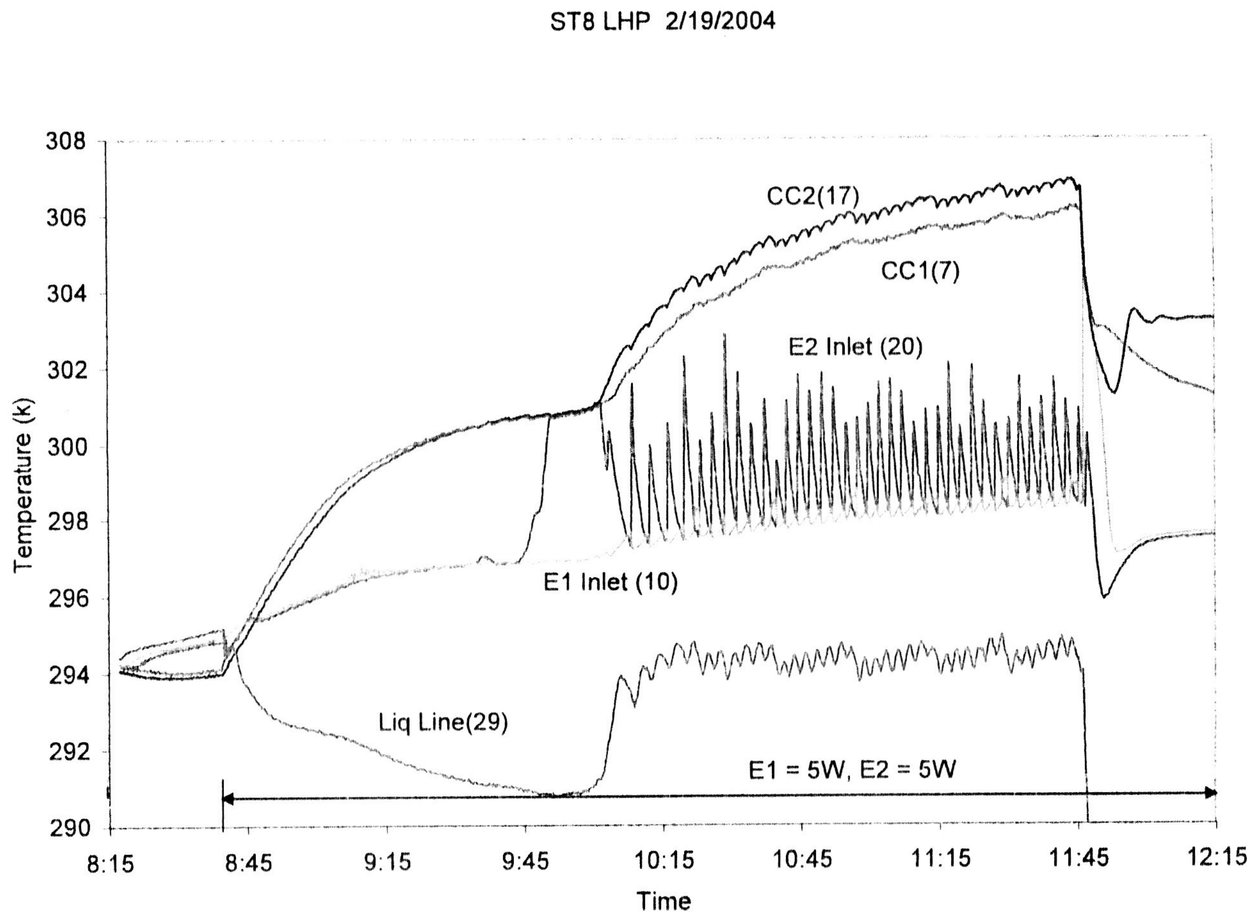
(5W/5W, 273K/273K, Horizontal, No TEC Control)



- In most cases, MLHP start successfully without using TECs
- There were a few cases where TECs were used to achieve successful start-ups.

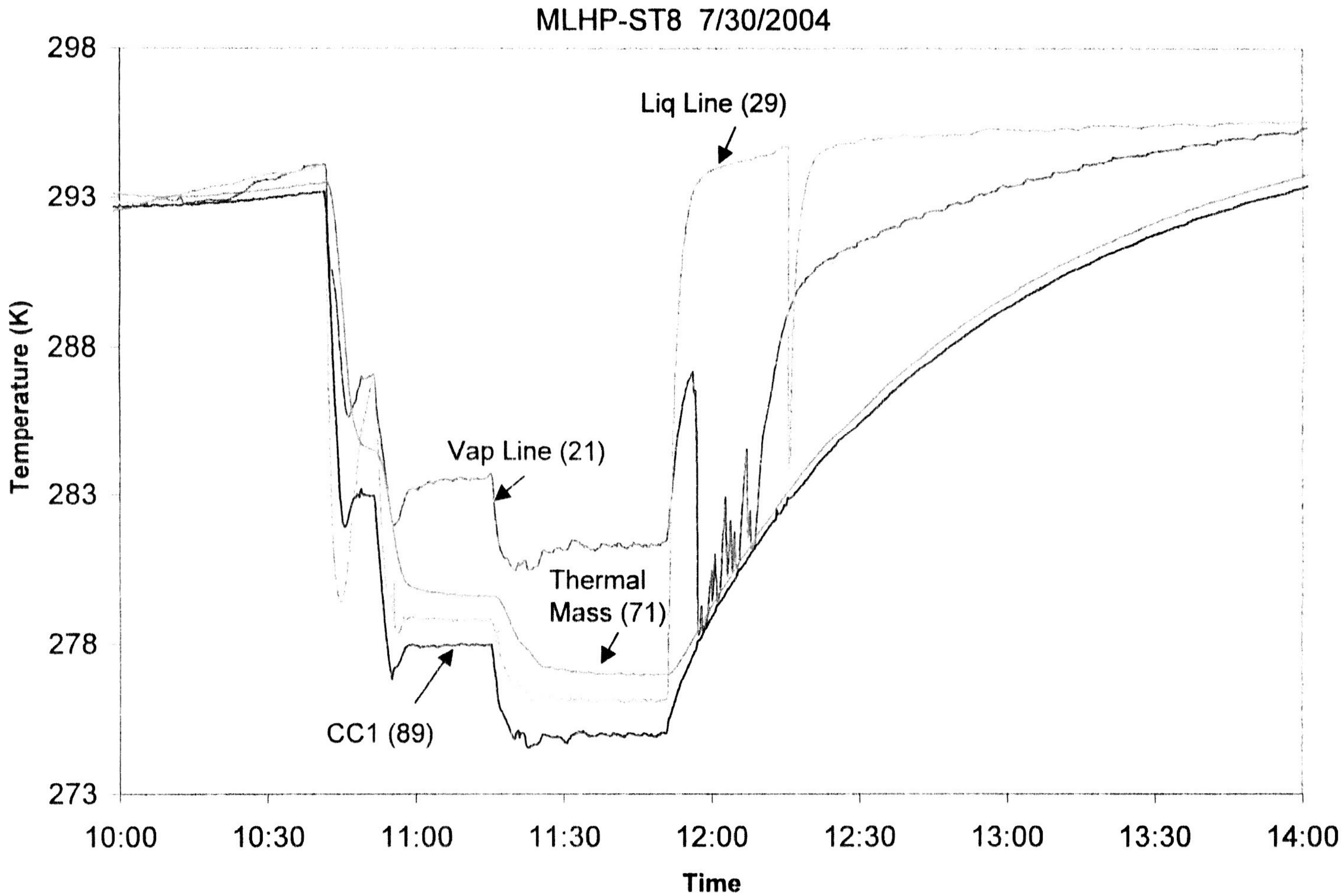
MLHP Test Results - Star-up

(5W/5W, 273K/273K, Condensers Slightly above Evaporators)



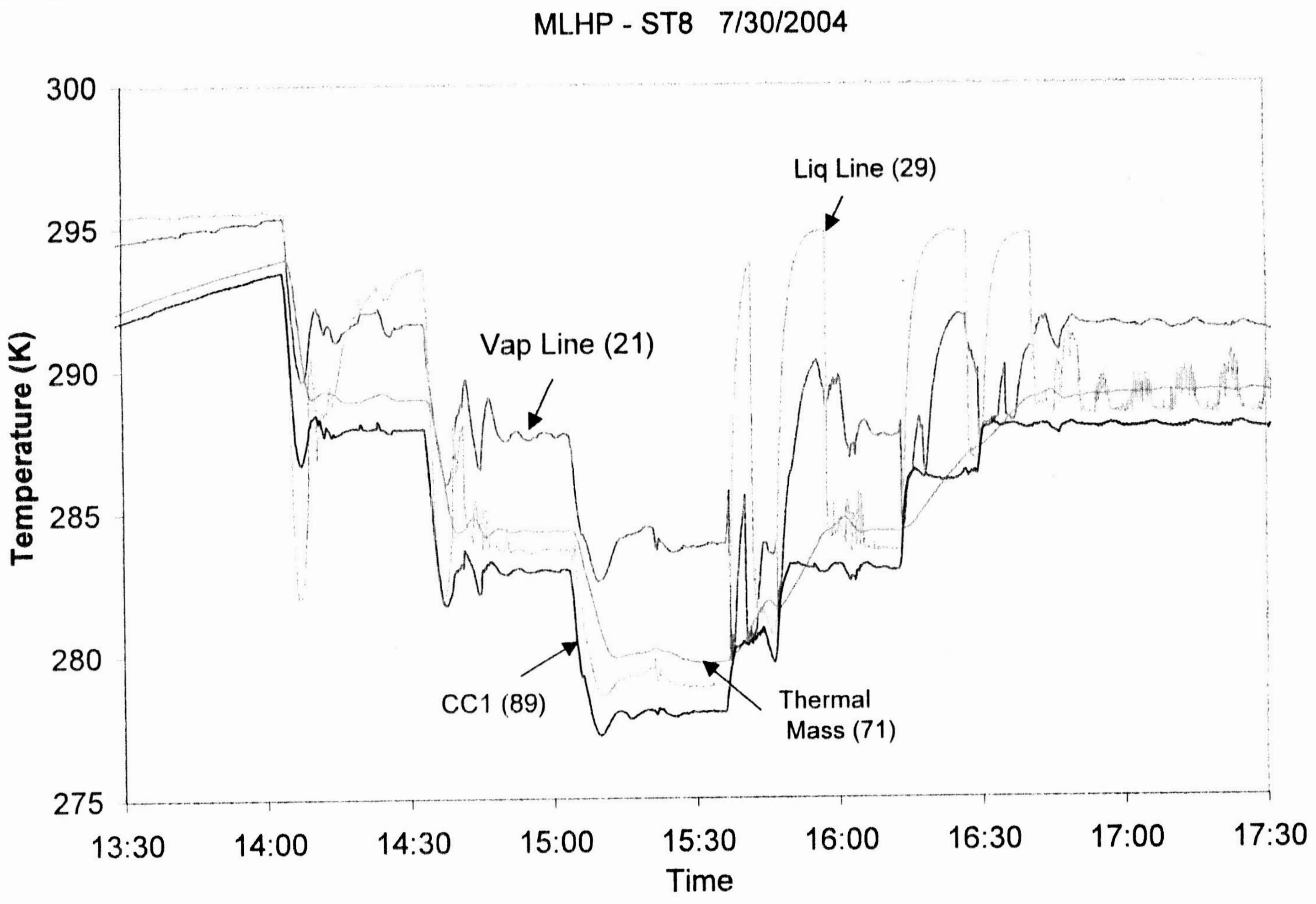
- CC2 could not reach a steady temperature and E2 was drying out
- At 11:45, TEC2 was turned on and set at 303K . Loop operated steadily afterwards.

MLHP Test Results – Starts and Operates on Parasitics



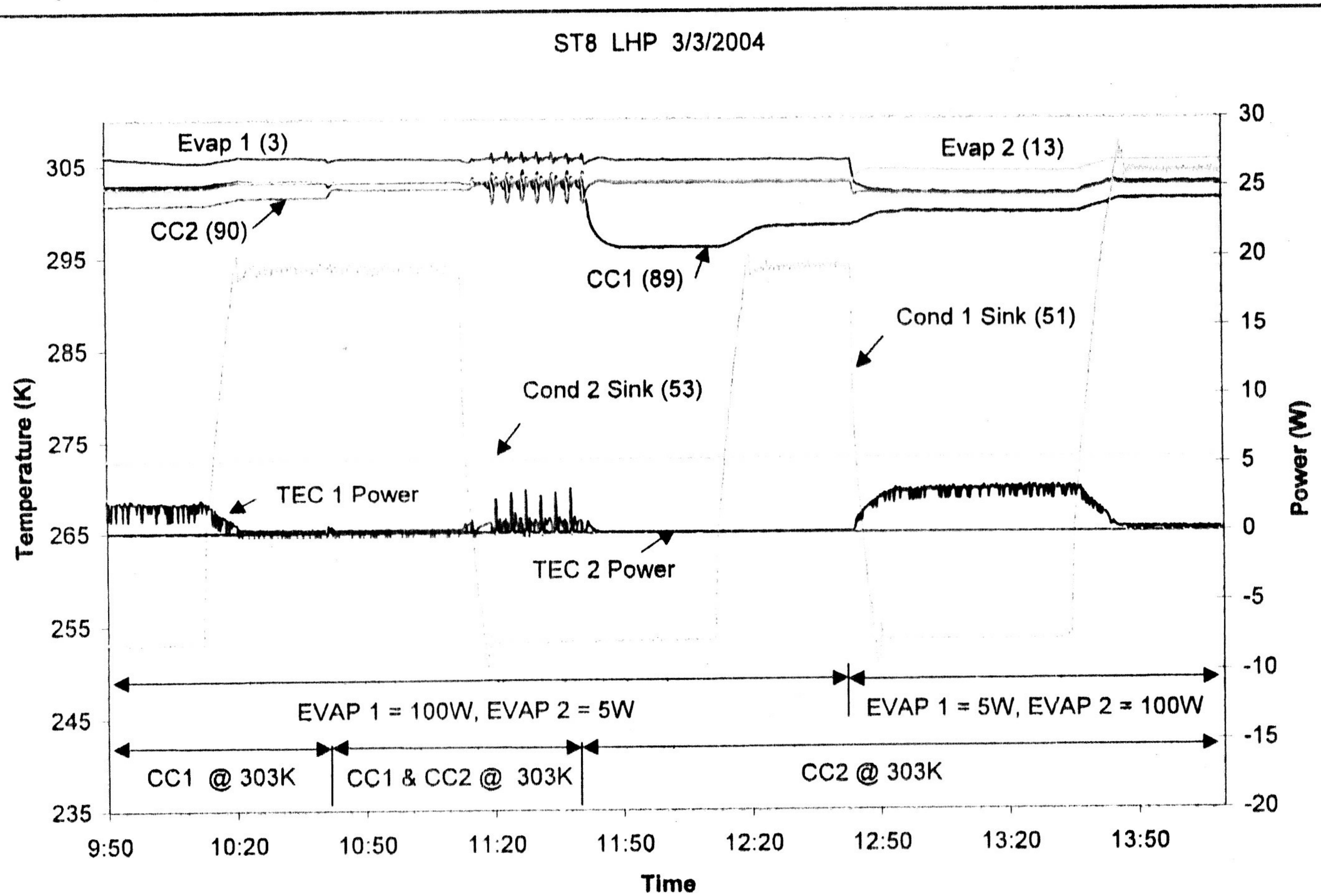
CC1 and CC2: No Control/ 283K/278K/275K/No Control

MLHP Test Results – Starts and Operates on Parasitics



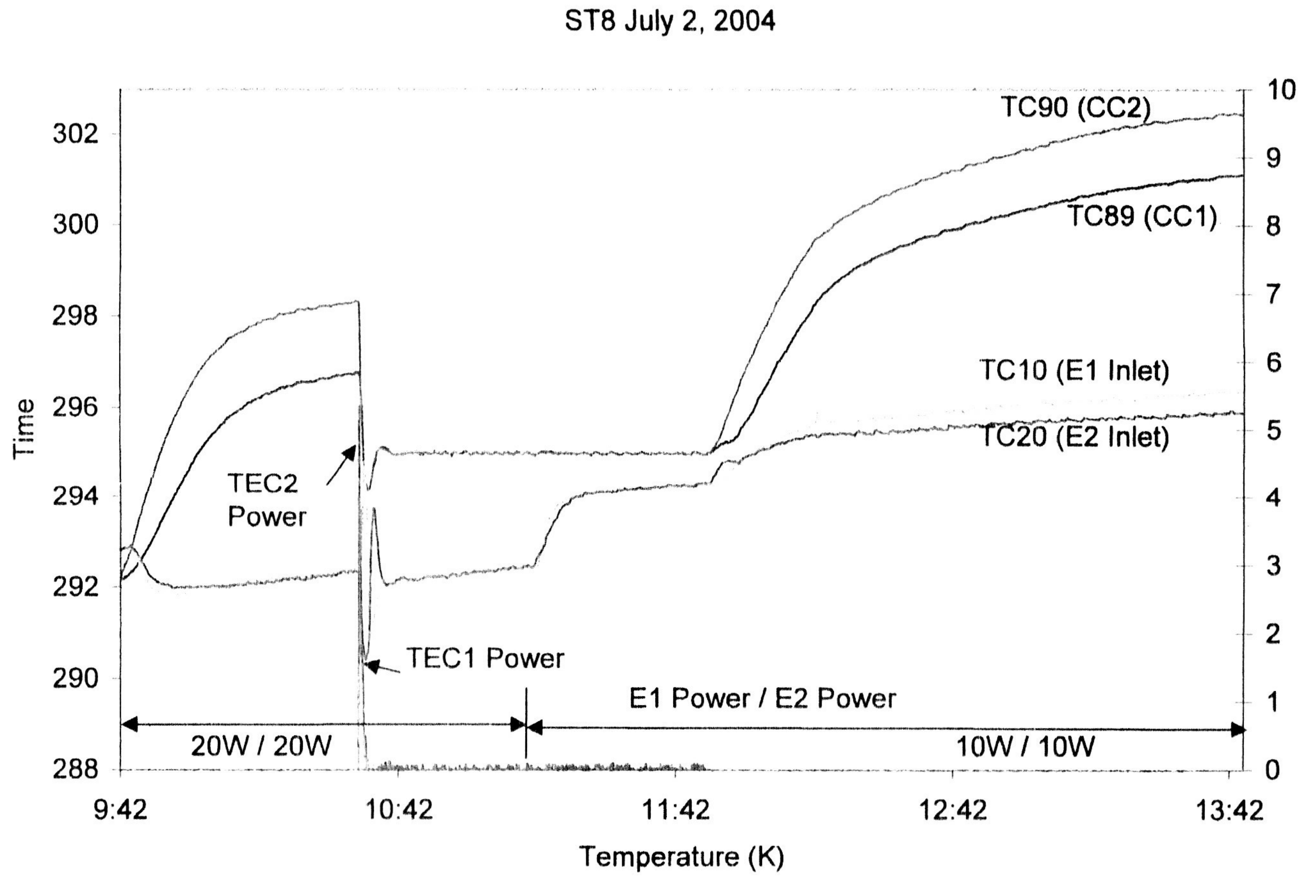
CC1 and CC2: No Control/ 288K/ 283K/ 278K/ 280K/ 283K/ 286K/ 288K

MLHP Test Results – Temperature Control
(CC1, CC2, or CC1/CC2 Control Set at 303K, E1/E2 Power Varied)



- **Loop operated stably at 303K**
  - **Alternate CC1 and/or CC2 control at 303K**
  - **Uneven heat loads at 100W/5W and 5W/100W; rapid power change**
  - **Uneven sink temperatures; rapid sink cycle between 253K and 293K**

MLHP Test Results – Temperature Control
(C1/C2 Sinks = 283K/283K)



- 9:40 – 10:37 No active control of CCs
- 10:37 – 11:48 CC1 and CC2 controlled at 295K
- 11:48 – 13:42 No active control of CCs
- TECs allowed the MLHP to operate at 295K

MLHP TEC Control Heater Power

303K CC2 Set Point

E2 Power (W)	TEC2 Power (W) @263K Sink	TEC2 Power (W) @273K Sink
20	0.3	0.2
40	0.8	0.6
60	2.0	1.5
80	3.2	2.4
100	3.5	2.8
120	3.8	2.6

Summary and Conclusions

- TECs can be used to enhance LHP start-up success.
  - Maintain a constant CC set point temperature
  - Lower the CC temperature
  - May eliminate the need for starter heaters
- TECs can be used to broaden the range for LHP operating temperature control.
  - Cooling mode: maintain CC temperature at low powers
  - Heating mode: reduce the required control heater power
- Experimental results with one-evaporator and one-condenser LHP
  - TEC can maintain the operating temperature within ±0.3K between heat loads of 0.5W and 100W.
  - TEC requires less than 1W over the entire power range.
- Experimental results with two-evaporator and two-condenser LHP
  - TEC can maintain the operating temperature within ±0.3K between heat loads of 5W and 120W.
  - TEC requires less than 4W over the power range.
  - TEC enables LHP to start and operate with parasitic heat gains alone (no power to the evaporators).